A MODIFIED TECHNIQUE IN RFID NETWORKING PLANNING AND OPTIMIZATION

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A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
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JANUARY 2015

ABSTRACT

Radio Frequency Identification (RFID) system is acknowledged as a mature technology often deployed in large scale tracking applications. Implementation issues like cost and effectiveness necessitated research on RFID Network Planning (RNP). The solution typically inspired by nature includes the use of Genetic Algorithm (GA), Bacteria Foraging Optimization (BFO) and Particle Swarm Optimization (PSO) Algorithm. In this research, PSO algorithm was used in the optimization process as it was considered as a very useful, efficient and well known algorithm. However, there are no parameters settings of PSO that fits all. This issue becomes more significant if PSO is used for solving complex optimization problem such as the RFID Network Planning (RNP). Any variation made to the values of PSO parameters (number of iterations, number of swarms, inertia weight value and correction factor value) will result in a huge difference to the output of the optimization process. In addition, RFID tag coverage optimization comes with another set of parameters to be considered such as the number of RFID readers, number of RFID tags and working space area. RFID tag coverage optimization is also considered as a high dimensional optimization process. To reduce the complexity of the optimization process, this research focuses on developing a method to determine the optimum setting for PSO parameters. Two sessions of Design of Experiment (DOE) analysis were embedded in the optimization process. Initially, the objective function was developed by elaborating the mathematical model of RFID tag coverage optimization. In order to get the general settings of PSO parameters, several RNP scenarios were generated by the first session of DOE and a Matlab code was developed for each scenario. For the second session of DOE, the results from the PSO optimization of each RNP scenario were analyzed using Minitab 16 software and the optimum settings of PSO parameters were identified. From here, the general settings of PSO parameters that can be applied to all scenarios are proposed. For the purpose of validation, the RFID tag coverage optimization

using PSO and DOE combinations was tested against two variants of PSO. The comparison tests were done for all RNP scenarios and from the experiment results, the combination of PSO and DOE manages to perform better compared to other PSO variants in the test of objective function value eventhough not the fastest. As a conclusion, the proposed method (PSO and DOE combination) can be considered as a robust and efficient optimization system because it manages to generate high quality results in overall RNP scenarios. Additionally, the spread of the generated results is small.

Keywords: RFID Network Planning, RFID Tag Coverage, Particle Swarm Optimization (PSO) Algorithm and Design of Experiment (DOE)

ABSTRAK

Sistem *Radio Frequency Identification* (RFID) kini dianggap sebagai teknologi yang matang dan ia sering digunakan dalam aplikasi berskala besar. Senario ini mengakibatkan masalah Perancangan Rangkaian RFID (RNP) yang semakin menular dan algoritma yang diilhamkan dari alam semulajadi (*Genetic Algorithm* (GA), *Bacteria Foraging Optimization* (BFO) dan *Particle Swarm Optimization* (PSO)) sering digunakan untuk menyelesaikan masalah RNP ini. Dalam kajian ini, algoritma PSO telah digunakan dalam proses pengoptimuman kerana algoritma ini cekap, efisien dan terkenal. Walaubagaimanapun, PSO tidak mempunyai penetapan parameter optimum yang sesuai untuk semua masalah pengoptimuman. Hal ini menjadi lebih kritikal jika PSO digunakan untuk masalah pengoptimuman yang kompleks seperti RNP kerana sebarang perubahan nilai yang kecil pada parameter-parameter PSO akan menghasilkan keputusan yang berbeza-beza. Selain parameter-parameter PSO (bilangan ulangan (*iterations*), bilangan kawanan (*swarms*), nilai *inertia weight* dan nilai *correction factor*), RNP juga mempunyai beberapa parameter yang perlu diambil kira seperti bilangan alat pembaca, bilangan tag dan luas kawasan kerja. Selain itu, RNP juga dikategorikan sebagai masalah pengoptimuman kompleks dan berdimensi tinggi. Oleh itu, kajian ini bertujuan untuk membangunkan sebuah kaedah untuk mendapatkan penetapan (*setting*) yang umum bagi setiap parameter PSO bagi proses pengoptimuman liputan tag RFID. Dalam kaedah ini, dua sesi *Design of Experiment* (DOE) akan digunakan dalam proses pengoptimuman ini. Untuk permulaan, fungsi objektif perlu dibentuk dengan menghuraikan model matematik bagi liputan tag RFID. Proses penghuraian ini penting bagi mendedahkan kesemua lokasi parameter RNP supaya fungsi objektif berkenaan boleh digunakan untuk proses pengoptimuman PSO. Bagi menjana penetapan yang umum, kajian ini mengambil kira beberapa senario RNP untuk dikaji dan kumpulan senario ini dijana menggunakan sesi pertama DOE. Kemudian, kod Matlab untuk proses pengoptimuman setiap senario dibangunkan. Seterusnya, untuk sesi kedua DOE,

keputusan yang dijana oleh proses pengoptimuman untuk setiap senario RNP akan dianalisa menggunakan perisian Minitab 16. Dalam sesi kedua DOE ini, penetapan optimum untuk setiap parameter PSO bagi setiap senario akan diketahui. Dari sini, penetapan umum bagi setiap parameter PSO juga telah diutarakan. Bagi proses validasi, proses pengoptimuman liputan tag RFID dengan penetapan parameter optimum (kombinasi PSO dan DOE) telah diuji dengan beberapa varian PSO yang lain. Hasil dari keputusan eksperimen, didapati kaedah pengoptimuman menggunakan gabungan PSO dan DOE berjaya menjana keputusan yang lebih baik bagi nilai fungsi objektif untuk setiap senario RNP walaupun bukan dalam masa yang terpantas. Kesimpulannya, kaedah pengoptimuman yang menggunakan kombinasi PSO dan DOE adalah cekap dan efisien kerana kaedah ini berpotensi untuk menjana keputusan-keputusan yang berkualiti tinggi bagi kesemua senario RNP. Selain itu, keputusan-keputusan yang dijana juga berada dalam julat yang rendah.

Kata kunci: Perancangan Rangkaian RFID (RNP), Liputan Tag RFID, Algoritma *Particle Swarm Optimization* (PSO) Algorithm and *Design of Experiment* (DOE)

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LIST OF SYMBOLS AND ABBREVIATIONS

RFID	-	Radio Frequency Identification
RNP	-	RFID Network Planning
PSO	-	Particle Swarm Optimization
DOE	-	Design of Experiments
GA	-	Genetic Algorithm
UTHM	-	Universiti Tun Hussein Onn Malaysia
ANN	-	Artifical Neural Networks
DE	-	Differential Evolution
IT	-	Information Technology
ISS	-	International Space Station
SAW	-	Surface Acoustic Waves
GPS	-	Global Positioning System
QoS	-	Quality of Service
IDENTEC	-	An RFID solution provider
SDK	-	Software Development Kit
RGA	-	Real-code Genetic Algorithm
ES	-	Evolution Strategy
SA-ES	-	Self Adaptation Evolution Strategy
CPSO	-	Canonical Particle Swarm Optimization
MCPSO	-	Multi-swarm Cooperative Particle Optimization
MC-BFO	-	Multi-colony Bacteria Foraging Optimization
MGA	-	Modifies Genetic Algorithm

Pt	-	Transmitted (reader) power
Gt	-	Transmitter(reader) antenna gain
Gr	-	Receiver (tag) antenna gain
D	-	Distance between transmitter and receiver
Λ	-	Radio wavelength
N_T	-	Number of tags
P_i^r	-	Received power at each tag (dBm)
P_d	-	Threshold power (minimum power to start communication) (dBm)
dBi	-	Comparison between antenna gain and isotropic radiator
dBd	-	Comparison between antenna gain and reference dipole
α_{BW}	-	Spectrum power
E_{tag}	-	Tag effective power reflection coefficient
P_{TX}	-	Transmitter (tag) transmit power
G_T	-	Transmitter (tag) antenna gain
G_R	-	Receiver (reader) antenna gain
$PL(x)$	-	Path-loss for the distance between reader and tag
M	-	Number of readers
$dist(\quad)$	-	Function to compute distance
R_i, R_j	-	Positions of ith and jth reader respectively
r_i, r_j	-	Interference range of ith and jth reader respectively
$\gamma(p)$	-	Readers interference at point p
RT	-	All tag read test points in the working area
$Cd_{r,p}$	-	Signal strength at receiver (tag) from the desired reader
$Cd_{rj,p}$	-	Signal strength at receiver (tag) from other reader, Reader j
Sm	-	Sensitivity threshold
$v(t+1)$	-	New velocity
w	-	Inertia weight

$v(t)$ - Current velocity

R - Random variable (0 to 1)

c_1 - Cognitive weight

$p(t)$ - Personal best known position

$x(t)$ - Current position

c_2 - Social weight

$g(t)$ - Global best known position

$x(t+1)$ - New position

AMPS - Advanced Mobile Phone System

FDMA - Frequency Division Multiple Access

Mobitex - A wireless network architecture

DataTAC - A wireless data network technology

NMT - Nordic Mobile Telephone

TACS - Total Access Communication System

CDMA - Code Division Multiple Access

GSM - Global System for Mobile Communication

IDEN - Integrated Digital Enhanced Network

PCS - Personal Communication Service

TDMA - Time Division Multiple Access

GPRS - General Packet Radio Service

HSCSD - High-Speed Circuit-Switched Data

EDGE - Enhanced Data for Global Evolution

WiDEN - Wideband Integrated Digital Enhanced Network

UMTS - Universal Mobile Telecommunications System

WCDMA - Wideband Code Division Multiple Access

LTE - Long Term Evolution

WiMAX - Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

RFID is very magical. These words were quoted from Dr. Bill Hardgrave, the founder of the RFID Research Center at the University of Arkansas. The center had a strong collaboration with Wal-Mart, the first company to implement RFID in a large scale. Dr. Hardgrave strongly believes that RFID will be used during the direct checkout of any retailer and the customers can do the purchase with using only the mobile phones or kiosks (Bustillo, 2010; Delen, Sharda, and Hardgrave, 2011).

Fortunately, his vision managed to become a reality in various retailers located in the United States of America and some European countries. Additionally, RFID is also widely used in the supply chain and production processes in various industries (S. A. Ahson and Ilyas, 2010; Bolic, Simplot-Ryl, and Stojmenovic, 2010).

The application of RFID technology in the supply chain was steadily increased and the need to detect assets in a large area is becoming essential. This scenario applies in the automated inventory management system and product receiving (Qiang, Yu, Yiping, and Wenshneg, 2006). The increasing trend of RFID deployment is due to the reduced cost of the equipments and the established global standard that applies to most RFID systems. This is the result from years of extensive researches.

RFID system is very excellent for various applications in the manufacturing industry such as for tracking work in progress (WIP), eliminating bottlenecks, tracking finished goods and measuring the inventory level. In automotive related systems, RFID technology serves as the main component in the engine immobilization system. In the supply chain management (SCM) industry, RFID system can be used in various processes such as shipping and receiving, warehousing, retail outlet and inventory management. As for the inventory management, RFID system is deployed for the asset recall and return management. In addition, RFID system is also deployed by airline industries for tracking baggage (Brown, Patadia, and Dua, 2007). From here, it can be concluded that the statement from Dr. Hardgrave is true.

1.1 Challenges of Large Scale RFID Deployment

An increasing number of companies start to deploy RFID technology in a large scale. This is a sign that the cost of RFID technology has become more affordable for most companies. After years of RFID industrial debut, the cost of passive tag is continuously decreased and fall into the 'comfort zone' of many companies and firms. In addition, the sensitivity of the chip in the RFID tag is also improving. After years of technological enhancement, RFID technology offers a much better coverage and enhanced readability. One example of a large scale RFID success story is the METRO Group (S. A. Ahson and Ilyas, 2010; Polycarpou, *et al.*, 2012). Upon deploying the RFID system, this company enjoyed various benefits such as the reduction in labor, time savings, efficient handling process and reducing out-of-stock (Polycarpou, *et al.*, 2012).

RFID technology is an established technology and the equipments of RFID are mostly ready for industrial applications. To deploy this technology in a small scale is relatively simple because the complexity of the system is still at the 'manageable' level. However, as mentioned before, most corporations and companies tend to deploy the system in a large scale. This means that the number of RFID equipments (reader, tag, antenna, middleware and others) is relatively huge. In other words, the complexity of the RFID system is increasing because of the significant needs for deploying a huge number of RFID readers without issues.

Additionally, the detection range for an RFID system is relatively limited for the time being. As a result, more RFID readers are needed in order to cover a large area. There are also some challenges that need to be considered such as the optimal tag coverage, readers collision avoidance, cost efficiency and good load balance (Ben, Wong, Yujuan, and Li, 2009; I. Bhattacharya and U.K. Roy, 2010; H. Chen and Y. Zhu, 2008; Chen, Zhu, and Hu, 2010; Chen, Zhu, Hu, and Ku, 2011; Di Giampaolo, Forni, and Marrocco, 2010; Y. Gong, Shen, Zhang, Chen, and Zhan, 2011; Leong, Ng, and Cole, 2005, 2006; Lin and Lin, 2007; Qiang, *et al.*, 2006; Yahui, Yujie, Min, and Zhijing, 2009). These challenges formed a new branch of knowledge named RFID Network Planning (RNP). RNP is very crucial before deploying an RFID system because RNP focuses on solving the challenges mentioned above.

A good RNP solution will optimize the RFID system and minimize the system interference to other RF systems in the surroundings (Leong, *et al.*, 2006). It will also ensure an acceptable Quality of Service (QoS) by minimizing the interference between RFID readers (Qiang, *et al.*, 2006). According to Chen, Zhu *et al* (2010), RNP problems need to be solved before installing RFID system in order to make sure the system operate optimally.

From the literature, RNP is a multi objective optimization function and the solution is in the form of the best location and power setting for each reader. As a result, in order to determine the best locations for readers those satisfy RNP challenges mentioned above, Nature Inspired Algorithms were employed (Genetic Algorithm, Bacteria Foraging Algorithm and Particle Swarm Optimization Algorithm) (Indrajit Bhattacharya and Uttam Kumar Roy, 2010).

In this research, Particle Swarm Optimization (PSO) was chosen as the base platform for solving RNP challenges (problems). This research focuses on the first RNP objective mentioned above (Optimal tag coverage). The reason for choosing RFID tag coverage is due to the fact that this objective is the most crucial among other RNP objectives (Di Giampaolo, *et al.*, 2010; Guan, Liu, Yang, and Yu, 2006).

1.2 Parameter Tuning Weakness of PSO Algorithm

PSO algorithm is an optimization technique that is based on a population system. This algorithm is inspired by the movement of birds and fishes in their own groups (Kennedy and Eberhart, 1995).

PSO also owns several advantages compared to Genetic Algorithm (GA) such as faster speed, easier to implement and fewer parameters to be adjusted (Chamaani, Mirtaheri, Teshnehlab, and Shooredeli, 2007; Khare and Rangnekar, 2012; Mei-Ping and Guo-Chang, 2004). According to Eberhart (2001), PSO is also considered as conceptually simple, easy to use and effectively works on various optimization problems (Eberhart, Shi, and Kennedy, 2001). PSO is also easy to modify/alter in order to fulfill different needs. This is due to the less number of parameters to be considered.

Although PSO is considered as an established optimization algorithm, it does not have the parameter tuning that fits all optimization problems. The PSO's parameters that require a proper tuning are the number of iterations, number of swarms, inertia weight value and correction factor value (El-Gallad, El-Hawary, Sallam, and Kalas, 2002; Kramer, Gloger, and Goebels, 2007). In some optimization problem, these parameters need to be set to the optimum value in order to get the best result (Beielstein, Parsopoulos, and Vrahatis, 2002).

The issue of parameter tuning weakness will worsen if PSO is used to optimize the RFID tag coverage. This is due to the fact that the RFID tag coverage optimization is a very complex optimization problem due to the high dimensional characteristic. Besides the parameter of PSO, the optimization problem also has several parameters to be considered such as the number of tags, number of readers and working space area.

In the RFID tag coverage optimization, the setting of parameters is very critical. This is because the RFID system is highly intricate and it has to be planned very properly. If the system works correctly, the business owner can be considered as a very fortunate person. However, if the RFID system fails to fulfill its objectives, the system will be a huge burden to the corporation or company.

In the parameter tuning process, any slight changes to the parameters will affect the end results greatly. This kind of uncertainty should not have bothered a highly complex system such as the RFID system. As a result, prospective companies and corporations are in urgency to have a reliable RFID planning system.

In order to enhance the parameter tuning of PSO, this research tends to propose a novel parameter tuning method. This method will improve the reliability and accuracy of PSO algorithm for the purpose of optimizing the RFID tag coverage. To do that, a number of research questions need to be taken into account. The research questions are as follows:

1) How to prepare an objective function to be optimized by the PSO algorithm?
2) What is the best parameter tuning for PSO in optimizing the RFID tag coverage?
3) Is there any parameter tuning of PSO that fit all RNP conditions?
4) What are the significant parameters of PSO?
5) How to quantify the value of parameter significance in PSO?

These questions can be considered as the guidance to develop the novel parameter tuning method for PSO algorithm. This method should be applicable to all RNP conditions.

1.3 Research Objectives

This research comprises of several objectives:

i. To construct the objective function of the RFID tag coverage optimization that exposes the direct correlation between the parameters of RFID tag coverage and the solutions of PSO.

ii. To justify the best parameter tuning of PSO for solving RFID tag coverage optimization in all RNP conditions.

iii. To evaluate the performance of the proposed method against other PSO variants.

1.4 Research Scopes

This research consisted of several scopes:

i. In this research, the type of RFID tag in used was RFID passive tag. This kind of tag has no internal power source and it is powered by radio waves from readers. The type of antenna used is an isotropic radiator antenna.

ii. To represent all RNP conditions, several case studies (scenarios) were used. These scenarios are within a given scopes (refer Chapter 5).

iii. This research covers two categories of parameters: PSO and RNP parameters. Additionally, these parameters are set in a specific range. The name and range of each parameter can be seen in Table 1.1.

iv. The correction factor value (refer Table 1.1) represents two variables: Cognitive weight and Social weight. In this research, the values for both variables are set as equal. As a result, the value of the correction factor represents the values of both variables.

v. The RFID application focuses in this research was asset tracking and management. All readers are activated all the time in order to track tagged assets. The tagged assets are located around a working area. Due to that, all readers needed to be deployed in order to track the locations of tagged assets in a real time manner.

vi. This research only focuses on Particle Swarm Optimization (PSO) algorithm for solving RFID tag coverage optimization.

vii. This research uses the original version of PSO algorithm because this version is deemed suitable for all optimization fields (Beielstein*, et al.*, 2002; Y.-J. Gong*, et al.*, 2012). Additionally, by choosing the original version of PSO, this research acts as a starting point for using 2 DOE session in PSO. Although there are a lot of PSO variants produced by other researchers, the author tends to choose the original version because there is no guarantee that the other PSO variants can perform better compared to the original PSO in the field of RFID tag coverage optimization. According to the author's best knowledge, every PSO variant is developed for a particular usage and for now, the original version of PSO is the most suitable.

viii. Matlab software was used for writing the code and running the simulation. Prior to code writing in Matlab, a pseudo code of PSO algorithm were written.

ix. Minitab 16 software was used for performing DOE analysis and generating some useful graphs.

Table 1.1: Name and range for each parameter

No.	Name of parameter	Category	Range	Unit
1	Number of iterations	PSO parameter	50-200	Iterations
2	Number of swarms		50-200	Swarms
3	Inertia weight value		0.5-3.0	N.A.
4	Correction factor value		0.5-3.0	N.A.
5	Number of readers	RNP parameter	1-10	Readers
6	Number of tags		10-100	Tags
7	Working space area		5m×5m – 30m×30m	m^2

1.5 Thesis Organization

In this chapter, brief introductions about Radio Frequency Identification (RFID) technology, RFID network planning (RNP) and Particle Swarm Optimization (PSO) algorithm were discussed. The parameter tuning weakness of PSO was also elaborated. Moreover, additional information about this research such as the research objectives and scopes were also highlighted.

In the next chapter, some theories and significant contributions will be discussed that related to the RFID, RNP, RFID tag coverage optimization, Particle Swarm Optimization (PSO) and Design of Experiment (DOE). Additionally, any related studies that are significance to this research are also discussed.

The third chapter covers the general research methodology. In this chapter the processes for developing the research methodology are explained. The research flowchart with a greater level of details is also provided.

In the fourth chapter, the methodology for constructing the objective function of RFID tag coverage optimization is properly discussed. Additionally, the steps for developing the Matlab codes are also presented.

The integration between PSO and DOE is explained in the fifth chapter. This chapter will also discuss the parameter tuning method that is applicable to all RNP conditions.

The performance of the proposed method was measured in Chapter 6. This chapter is also considered as the chapter for the results and discussion. The performance comparison is also considered as the validation process.

Finally, the final chapter provides a conclusion for this research and some recommendations for future works. Moreover, the contributions made by this research will also be highlighted

.

CHAPTER 2

LITERATURE REVIEW

This chapter focuses on the important theories and knowledge related to the research topics such as the cellular network planning, RFID technology, RFID Network Planning (RNP), RFID Tag Coverage Optimization, Particle Swarm Optimization (PSO) algorithm and Design of Experiment (DOE) technique. Also presented are the related works and models that are strongly related to this research. The critical findings in this chapter will be used as the foundation for developing the research methodology.

2.1 Introduction to Cellular Network

A cellular network is a mobile network that is used to provide services from the base stations to the subscribers. The base stations have a limited power supply and they can only cover a limited geographical area. This area is also known as a cell. Since the base station owns a limited power, a concept of frequency reuse can be applied without causing any interference between the transmitters. The cellular network system is suitable for a radio wave related application with limited frequency resources (Laiho-Steffens, Wacker, and Aikio, 2000; L. Song and Shen, 2010; Wallace and Walton, 1994).

Each cell is set with different frequency in order to avoid interference and maximizing the bandwidth. A combination of cells enables the radio wave to cover a large geographical area. From here, any mobile devices such as mobile phones and pagers are able to establish the connection (communicate) with each other (Byoung-Seong, Jong-Gwan, and Han-Kyu, 2002; Fasbender, Reichert, Geulen, Hjelm, and Wierlemann, 1999).

The cellular network is improved from time to time. As a result, this network has a lot of generations (refer Table 2.1). Any ascending generation provides a faster connection and the ability to transfer a bigger amount of data (Hämäläinen, 2008b; Mishra, 2004).

Table 2.1: The generations of cellular network

Generation	**Description**	**Protocol**	**Maximum Speed**
1G	Analogue services to cell phones, voice only and no SMS or data services.	▪ AMPS ▪ DataTAC ▪ FDMA ▪ Mobitex ▪ NMT ▪ TACS	2.4 Kbps
2G	The transition from analogue to digital services. The ability to store, copy, encrypt and compress data were provided.	▪ CDMA ▪ GSM ▪ IDEN ▪ PCS ▪ TDMA	20Kbps
2.5G	Introduction of packet switching of data other than circuit switching	▪ CDMA2000 1 x RTT ▪ GPRS ▪ HSCSD ▪ EDGE ▪ WiDEN	▪ 144Kbps ▪ 114Kbps ▪ 64Kbps ▪ 384Kbps ▪ 100Kbps
3G/ 3.5G/	Provide the mobile	▪ CDMA2000 EVDO	▪ 2.4Mbps

3.75G	broadband access to smart phones and modem	▪ CDMA2000 EVDV ▪ UMTS ▪ WCDMA ▪ CDMA2000/ EVDO-Rev A	▪ 2.4Mbps ▪ 2Mbps ▪ 2Mbps ▪ 3.1Mbps
4G	Provide faster mobile broadband access to smart phones and modem	▪ LTE ▪ WiMAX	▪ 100Mbps ▪ 128Mbps

The cellular network is deployed in a very large geographical area. This network is also very synonym to the extremely large scale deployment. As a result, the planning and optimization of cellular network is a topic that may not see any end. This is due to the fact that the parameters for the planning process keep changing and expanding such as the number of subscribers, the density of transceivers, the speed of packet data and the introduction of new cellular generations that will never be stopped (Amaldi, Capone, Malucelli, and Mannino, 2006; Elkamchouchi, Elragal, and Makar, 2007).

2.2 Cellular Network Planning

Cellular network planning is crucial for obtaining the sufficient network coverage. It can also offers a mobile network service with an acceptable Quality of Service (QoS). The quality of voice and data services manage to fulfill the expectation of subscribers and the network providers will be able to maintain their market share.

Another aspect for consideration is the economical efficiency for the construction of the network's infrastructure. It is worth to note that the cost for building a base station is very high. As a result, the number of base stations should be optimized in order to control the construction and management cost. On top of that, the signal interference should be reduced as it will jeopardize the life span of the whole system (Byoung-Seong, *et al.*, 2002; A. Wacker, Laiho-Steffens, Sipila, and Jasberg, 1999).

The cellular network planning is also considered as a highly complex process. The planned network's infrastructure should be flexible in order to cater the future demand of a faster data transfer. This is due to the fact that the number of subscribers and coverage area will keep expanding. A good network planning will yield an infrastructure that is easy to maintain and expand. Additionally, in order to fulfill certain demands, an excellent network infrastructure will need fewer modifications to be made to the existing infrastructure (Tutschku, 1998; Wallace and Walton, 1994). The methods for performing cellular network planning are shown in Figure 2.1.

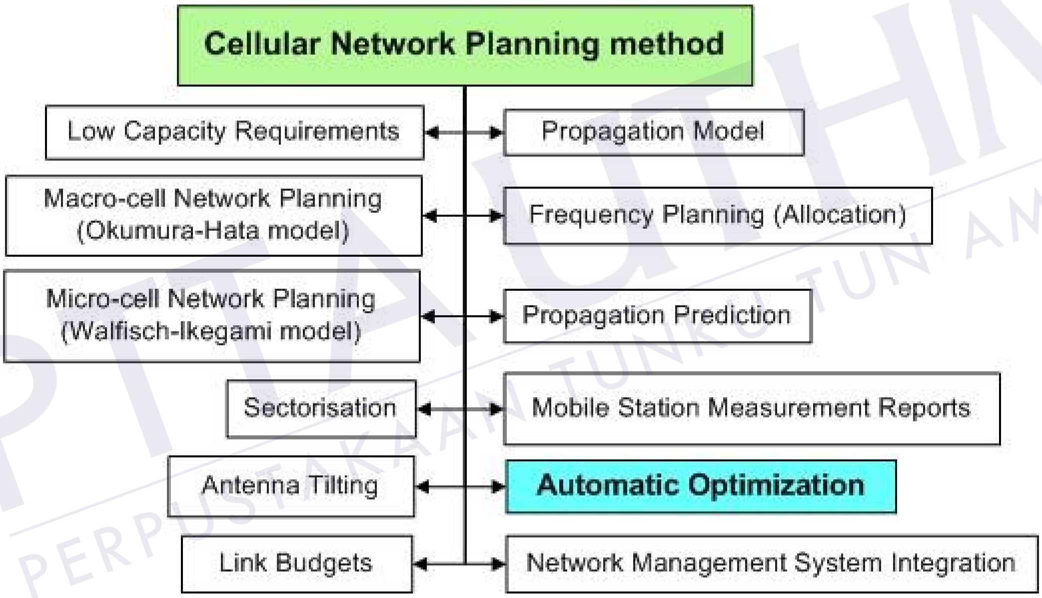

Figure 2.1: Various types of methods are available for cellular network planning (Laiho and Wacker, 2001; Laiho, Wacker, and Novosad, 2006; Mishra, 2004)

Based on the figure, some of the methods were developed during the 1st generation of cellular network. The methods are low capacity requirement, Okumura-Hata model and Walfisch-Ikegami model. The low capacity requirement was used to plan the first version of analog networks. During that time, the main objective of cellular network planning is to provide the optimal coverage to the subscribers. There is no issue related to the signal interference and data traffic because the number of subscribers is not really significant (Gamst, 1987; Laiho, *et al.*, 2006).

The Okumura-Hata model is still in use for planning the macro-cell network. There are certain enhancement made by the previous researchers in order to made the model accepted in a better way (Castro, Gomes, Ribeiro, and Cavalcante, 2010; Priya, 2010). As a result, this model is compatible with the 3G network.

In the Walfisch-Ikegami model, the main assumption is the transmitter's antenna is located on a rooftop and the radio wave is transmitted in multiple directions. This assumption is crucial for minimizing the traffic density. This model also utilizes the path loss formulation from the Walfisch-Bertoni model (Har, Watson, and Chadney, 1999; Laiho*, et al.*, 2006). In the Walfisch-Ikegami model, the parameters in consideration are the height of buildings and the distances between buildings. Moreover, this model also considers additional factors such as the used frequency, street orientation and antenna's height (Rozal and Pelaes, 2007).

The sectorisation method is able to reduce the interference between transmitters (base stations). The issue related to the signal interference becomes more prominent as the increasing number of subscribers in the 2G network yielded a higher site density. The sectorisation method is able to yield a denser environment of frequency reuse. This is possible because the omni-directional antenna in the base station is replaced with three sector antennas with 120° opening. Each antenna formed a new sector and each sector can be considered as a new cell. Moreover, each sector can be set with its own frequency. Sectorisation is also cost effective because it does not need the construction of a new base station (Achim Wacker, Laiho-Steffens, Sipila, and Heiska, 1999; S.-W. Wang and Wang, 1993).

Link budget is the analysis to be performed before commencing the network planning process. The link budget formulation is related to the magnitude of signal strength. Moreover, this method is still in use until today. In the link budget analysis, the parameters of interest are the receiver sensitivity, path loss, noise, antenna loss and cable loss. Additionally, the gains and losses from the transmitter is also calculated (Hämäläinen, 2008a; Nuza and Mazrekaj, 2012).

Propagation models are useful for the analysis of higher site densities. These models utilize the concept of ray tracing (Hämäläinen, 2008b). The frequency planning method is very useful for fulfilling the increasing capacity demands. In the method, the frequency reuse distance is calculated and the repeat cell pattern is determined. The frequency is also divided into homogenous groups before being inputted into the planning tool. At the end of the analysis, the C/I and C/A plots are generated for the result checking and fault detection processes (Elayoubi, Ben Haddada, and Fourestié, 2008; L.-C. Wang, Stuber, and Lea, 1997).

In order to improve the spectrum efficiency in GSM and saving some analysis time, the automatic frequency planning system was introduced. Moreover, the cellular network planning can also be done using the mobile station measurement reports. The reports are useful for assisting the network control process such as the planning and optimization stages (Barco, Canete, Diez, Ferrer, and Wille, 2001; Wille and King, 1998).

One of the most recent methods in cellular network planning is the automatic optimization. In this method, algorithms are used to run the analysis. The current trend in automatic optimization is the application of nature inspired algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Bacteria Foraging Optimization (BFO), Artificial Bee Colony (ABC) and Firefly algorithm. These algorithms are also becoming the backbones of the network planning software (Elkamchouchi, *et al.*, 2007; Riaz, Imran, and Hoshyar, 2010). Based on the explanation of the methods in cellular network planning, it can be seen that this research fall into the scope of automatic optimization (refer Figure 2.1)

2.2.1 The Importance of Cellular Network Planning

The main aim of network planning is to fulfill the customers demand with an acceptable Quality of Service (QoS). This is crucial for the network providers to avoid losing their market share (Amaldi, *et al.*, 2006; Qiang, *et al.*, 2006). Additionally, the cellular network planning yields the ability to deal with the interference from other signals (Gamst, 1987; L. Song and Shen, 2010).

The newer generations of cellular networks are faster and carry higher data volumes. Additionally, the number of subscribers is also increasing rapidly. This scenario demands the enhanced version of cellular network planning system. Since the parameters for cellular network keep changing and expanding, the development of cellular network planning systems will not come to an end (Rahman, Matin, and Rahman, 2013).

The cost and complexity of a network are highly dependent on the number of readers (transmitter). A good planning system is able to optimize the number of transmitters needed and from here; the cost and complexity of network will be under control (Corre and Lostanlen, 2009; Engels and Sarma, 2002; Qiang, *et al.*, 2006).

The continuous development in the cellular network pushes the performance of the information technology system to a higher level. To complement the continuous stream of information to the subscribers, the concept of the internet of things was born. In this concept, a technology known as the Radio Frequency Identification (RFID) is heavily exploited. The RFID technology is very efficient for the purpose of tracking and managing the assets and it has become increasingly famous among companies, organizations, retailers and others (Bolic, Simplot-Ryl, *et al.*, 2010; Hasnan, Bareduan, Nawawi, and Sidek, 2013; Nawawi, Hasnan, and Ahmad Bareduan, 2011; Sarma, 2004).

2.2.2 The Relation between Cellular Network and RFID Technology

As mentioned in the previous section, the needs to track and manage the assets are blooming along the continuous development of cellular network technology. The subscribers (customers) of the cellular network services demand a faster mobile internet connection. This trend is predictable since the shocking number of smart phones purchases. Along with the trend, the needs for a real time assets tracking and management are also on the rise. There are more companies started to implement the RFID system in their supply chain. This growing trend is also assisted by the escalating number of activities related to online shopping and rapid advertisement approach (Huseynov and Yıldırım, 2014; Malviya and Sawant, 2014).

The concept of the internet of things offers the ability of assets to "communicate" wirelessly. This scenario opens a new horizon to the development of the cellular networks. Moreover, the principles used in the cellular network are applicable to the RFID network. This is because both networks reside in the same category (UHF to LF) as seen in the electromagnetic spectrum (refer Figure 2.2). Additionally, the Friis transmission equation (Equation (2.1)) is used in both networks for the purpose of mathematical models development (Chen*, et al.*, 2011; D. Dobkin, 2008; Laiho*, et al.*, 2006). Both networks also have the same goal: To achieve the acceptable Quality of Service (QoS) (Levis, Johnson, and Teixeira, 2010; Qiang*, et al.*, 2006).

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \tag{2.1}$$

Notation	P_r	: Power input at receiving antenna
	P_t	: Power output at transmitting antenna
	G_t	: Transmitting antenna gain
	G_r	: Receiving antenna gain
	λ	: Wavelength
	R	: Distance between antennas

In RFID technology, an RFID reader (transmitter) emits a radio wave signal and the signal will be received by an RFID tag (receiver). To complete the cycle of communication, the signal from the reader is used by the tag to power itself and with the remaining energy from the signal; the tag will bounce the signal back to the reader. In this "reply" signal, the ID of the tag will be carried over. This reply signal is also considered as the uplink signal (Harvey Lehpamer, 2012; Albert Lozano-Nieto, 2011; Nawawi*, et al.*, 2011). Unlike the cellular network, the uplink signal of an RFID system has to be taken into consideration (Qiang*, et al.*, 2006).

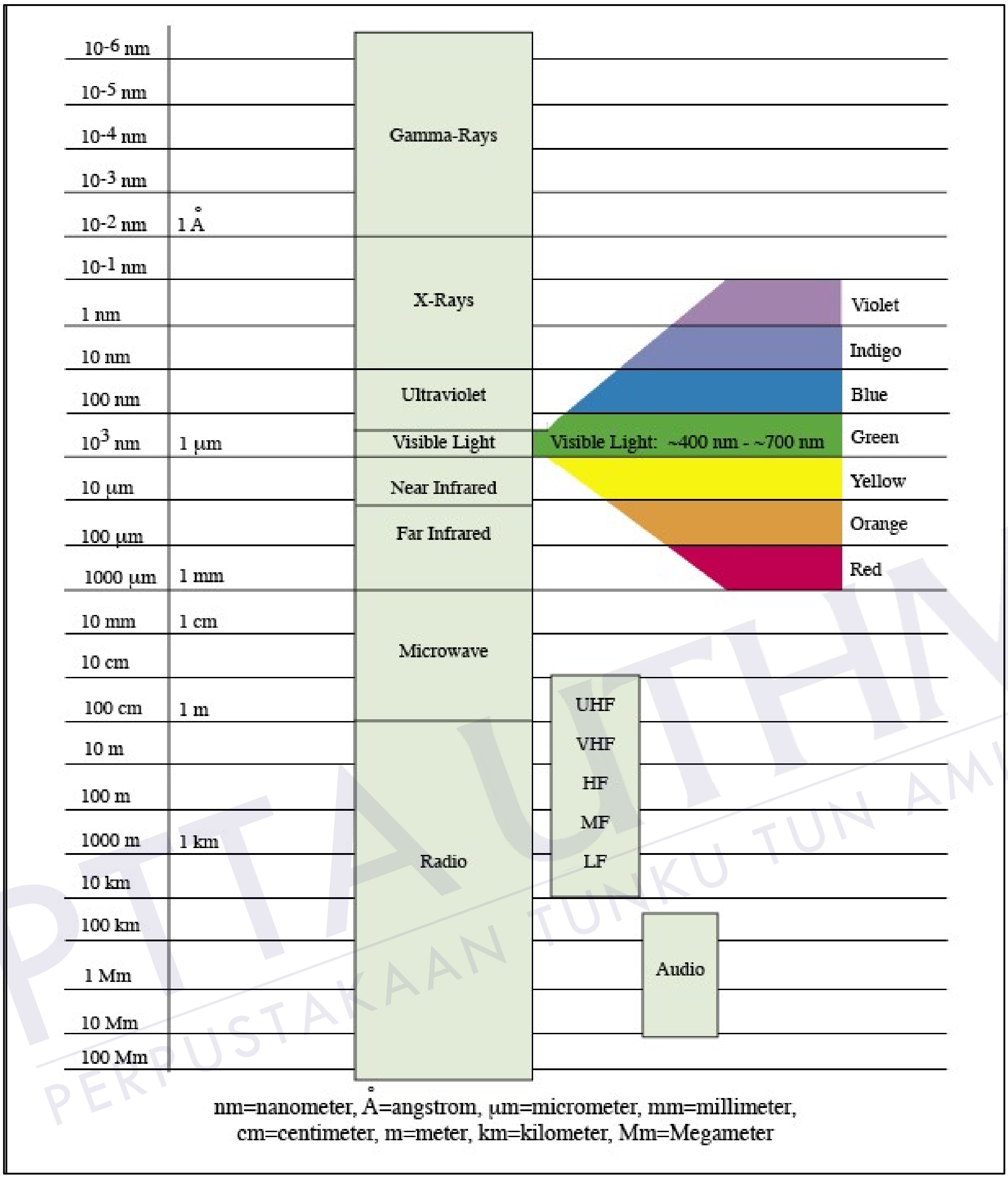

Figure 2.2: The Electromagnetic Spectrum (LASP)

RFID system is more favorable nowadays because it offers the ability to track assets in a real time manner. RFID system is also becoming the main backbone for establishing the concept of the internet of things. In this concept, any tagged assets exist virtually and the management of the assets can be done anywhere on the globe (Miles, Sarma, and Williams, 2008; Sarma, 2004). Currently, the RFID system is on its way to be fully integrated in the supply chain industry. The integration processes are done in a very extensive way because the cost for deploying this technology is becoming more affordable to the masses (Bolic, Simplot-Ryl, *et al.*, 2010). The next section uncovers some details about the RFID system.

2.3 Radio Frequency Identification (RFID) System

RFID is considered as a mature technology nowadays. This technology has a huge potential to solve the asset management related problems such as asset security, identification and tracking (Al-Ali, Sajwani, Al-Muhairi, and Shahenn, 2007). RFID is also able to speed up the process of checking and monitoring of tasks and provide real-time information about the process in interest (H. Chen and Y. Zhu, 2008; Mehrjerdi, 2009). RFID is a part of Auto-ID systems which consists of another identification elements such as smart cards and barcodes (Fuhrer, Guinard, and Liechti, 2006).

2.3.1 RFID Equipments

RFID technology is accepted by various organizations and this technology is expected to become our everyday life partners (Fuhrer, *et al.*, 2006). RFID system consists of three main elements (refer Figure 2.3): a tag, a reader and a middleware. The tag, also called a transponder, is made of a chip and an antenna. It contains a unique code that provides the unique identification of each object (Aysegul, Nabil, and Stephane, 2008; Qiang, *et al.*, 2006). The reader, also known as an interrogator has an antenna which emits radio signals and receive signal in return from the tag. The distance of the reading range depends on multiple factors; the frequency that is used, the orientation and polarization of the reader and the deployment environment (Aysegul, *et al.*, 2008). Lastly, the middleware can provide the primary link between RFID readers and databases (Fagui and Zhaowei, 2006). RFID technology can be divided into three categories: 1) RFID system operating frequency, 2) RFID tag power source and 3) Method of communication between tag and reader (Bolić, Athalye, and Li, 2010).

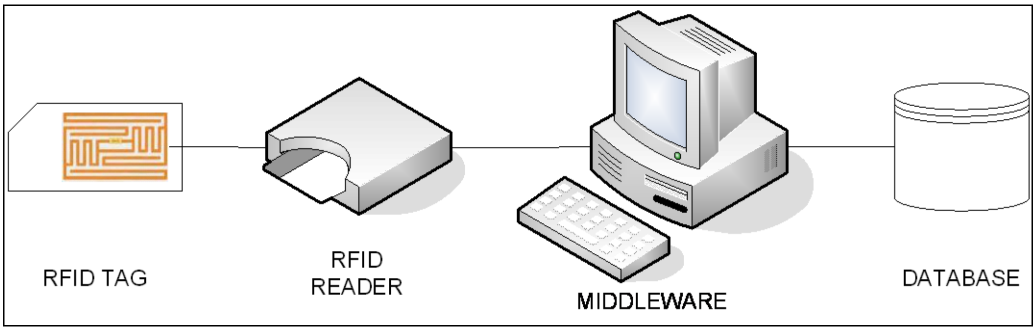

Figure 2.3: RFID System Components (Elshayeb, Hasnan, and Yen, 2009)

2.3.1.1 RFID Tag

An RFID tag generally contains an antenna and an electronic chip (Fuhrer*, et al.*, 2006). RFID tag communicates with the RFID reader using a method named Backscatter Modulation (Bolić*, et al.*, 2010; Qiang*, et al.*, 2006). In this kind of communication method, the tag is powered by radio wave transmitted to them by the RFID reader. This tag will send information back to reader using the radio wave reflection.

There are three (3) types of tags: Active, passive and semi-passive (Angeles, 2005). An active RFID tag is powered by a battery(Angeles, 2005). Thus, it needs a regular maintenance and active tag costs more than passive tag. In the other hand, an RFID passive tag is powered by radio waves emitted by RFID readers. This kind of tag will use the energy from the radio waves to send back signal to the RFID reader. The passive tag is preferred by most organizations because of its benefits such as low cost to deploy, no maintenance needed, small sized and less complex.

2.3.1.2 RFID Reader

An RFID reader is a very crucial component in an RFID system that located between the RFID tag and the event filter (Glover and Bhatt, 2006). It is used to generate and transmit radio frequency (RF) energy that will wake up the RFID tag. Another function of an RFID reader is to receive and decode backscatter signal received by the tag (Glover and Bhatt, 2006; Karmakar, 2010; Harvey Lehpamer, 2012). This reader and tag communication system is also known as a master-slave relationship with the reader acts as the master while the tag is the slave (Karmakar, 2010). In addition, an advanced version of an RFID reader has the capability to read and write data on the tag. For UHF readers, this task can be done within the frequency of 865-868 MHz for ETSI and 902-928 MHz for FCC (Siemens, 2012).

An RFID reader consists of three main parts: 1) Antenna, 2) Transceiver and 3) Control Section. The antenna is needed for sending and receiving RF signals. In order to generate RF signal for transmission and reception, the transceiver has to be in operation. The transceiver will operate under two signal path (signal from tag and signal to tag). The third part, the control section, consists of microprocessor, memory block, analog to digital converters and communication block (Karmakar, 2010). The control section, as it name suggests, perform several tasks such as operating signal modulation, initiating anti collision procedures and decoding received signal from tag. The microprocessor is used to decode data. This part also performs digital signal processing over received data from tag (Glover and Bhatt, 2006; Karmakar, 2010; Harvey Lehpamer, 2012; F. Wang and Liu, 2005a).

RFID readers can be divided into two main categories (fixed reader and mobile reader) (Harvey Lehpamer, 2012; Siemens, 2012). A fixed reader comes with cables for power supply and data transfer. This kind of reader is usually mounted on walls or doors. In the other hand, a mobile reader is also known as handheld RFID reader. A handheld reader is powered by a battery and it can transmit data wirelessly (Siemens, 2012).

There are two communication types for RFID readers which are *read-only* and *read-write*. For the read-only communication type, the reader will always transmit RF signal and receive backscatter (response) signal from tag. This type of communication is also called *tag talks first*. An RFID reader with read-write communication type will send command to tag before initiating reading or writing activity (A. Lozano-Nieto, 2010). As the RFID technology becomes matured, the speed of reading and writing to tag are significantly reduced and for some manufacturers, the reading rate is equal to the writing rate (Siemens, 2012). A detail classification of RFID readers can be seen in Figure 2.4 (Karmakar, 2010).

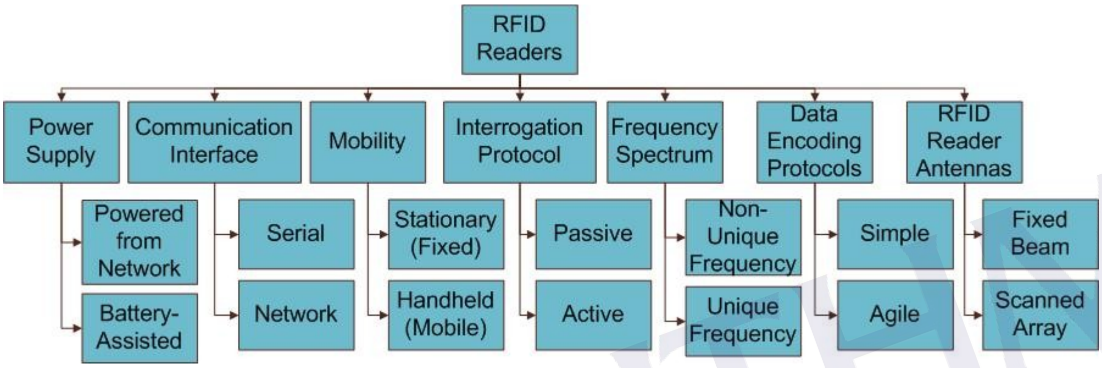

Figure 2.4: Classification of RFID Readers (Karmakar, 2010)

Applications of RFID readers are in numerous industries such as manufacturing, supply chain, logistics, retailers, transportation services and others. In the manufacturing industry, RFID readers are deployed in various locations around the manufacturing facility such as single reading stations, production processes, assembly processes, conveyor systems, inventory systems, material flow control and material handling systems. Other major applications of RFID readers are in the field of Supply Chain Management (SCM). In SCM, RFID readers are fixed on the forklifts, pallets, containers, trucks and gate entrance. RFID reader also finds its way to the distribution center and retailer outlets (Harvey Lehpamer, 2012; Siemens, 2012).

2.3.1.3 RFID Middleware

An RFID system will yield a large volume of data (F. Wang and Liu, 2005b). In order to utilize an RFID system, these data must have value and can assist the decision making processes. The main role of RFID middleware is to filter and process data that comes from deployed RFID readers. A middleware is able to sort and process data according to the system requirements (Bolić*, et al.*, 2010). These data must be presentable to the higher level software. A middleware will pilot the readers and process data from the reader so that the data will be useful for the decision maker (Fuhrer*, et al.*, 2006). Middleware will serve as bridges between the physical RFID world and the rest software infrastructure (F. Wang and Liu, 2005a).

According to Glover (2006), RFID middleware consists of three main components. The first is Application Level Interface that is used to summarize information from device interface. Besides, Event Manager is needed in a middleware for processing and filtering raw data from RFID reader. This step is crucial for providing meaningful information from the RFID reader and useful for decision making process. In order to allow the application level interface to manage RFID readers, a middleware must have the Reader Adapter.

2.4 The Horizon of RFID Technology

Low-cost RFID tag is capable of reading or writing the information of an entity without contact physically, while it possesses a fast recognition speed, and has a relatively greater storing ability compared with bar-code (Asif and Mandviwalla, 2005; Fagui and Zhaowei, 2006; Fuhrer*, et al.*, 2006; Glover and Bhatt, 2006). Data-on-tag can also be modified for information updating purpose (Bolić*, et al.*, 2010).

When using a bar-code system for detection purpose, label must be correctly positioned relatively to the reader. This characteristic is called Line of Sight which requires human intervention for scanning purpose and it will provide chance for error and inefficiencies (Al Kattan and Al-Khudairi, 2007; Fuhrer*, et al.*, 2006; Sahin, Dallery, and Gershwin, 2002). Using RFID, the RFID label or tag can be scanned from a greater distance and this will eliminate the need for Line of Sight (Al Kattan and Al-Khudairi, 2007; Angeles, 2005; Glover and Bhatt, 2006; F. Wang and Liu, 2005a).

RFID technology also offers a higher read rate compared to barcodes and more than one tag can be read simultaneously (Bolic, Athalye, and Li, 2010). This technology also capable of reading objects in motion and data-on-tag can be read under hard conditions (Fuhrer*, et al.*, 2006). With all of these advantages, RFID technology has a potential to achieve global asset visibility by automating and enhancing asset management system (Angeles, 2005; Bolić*, et al.*, 2010; Glover and Bhatt, 2006). In addition, RFID has the potential to bring new transparency to the supply chain (Asif and Mandviwalla, 2005; Clarke, Twede, Tazelaar, and Boyer, 2006).

Despite all the advantages offered by RFID technology, there are several challenges before implementing this technology. One main challenge is the non-compatibility between different operating frequencies. Communication between RFID equipments or devices will not initiate if the operating frequencies are different (Bolić*, et al.*, 2010). The operating frequencies are different according to RFID equipments manufacturers.

Furthermore, to implement the RFID system, considerable costs will be needed. In other words, adopting RFID in an existing system will cost a lot of funds. Due to that, a lot of planning tasks need to be executed before implementing such system. RFID adopters must not let their RFID system to fail easily. A study by Fred et al. (2007) focused on identifying IT problems and challenges before adopting RFID technology in a particular system. Fred mentioned that IT personnel must address the technology infrastructure, business processes and managerial issues of a particular system before implementing RFID into that particular system. Moreover, Fred also suggested that IT personnel need to gain knowledge about RFID data life cycle because they must take into consideration on how the data will be transferred in an RFID system. Data life cycle can be divided into six (6) stages (Fred, Richard, Roger, and Ik-Whan, 2007):

i. Source data acquisition (reading RFID data and integrating with other source data);
ii. Integrating source data with enterprise transactions systems;
iii. Integrating data across organizations;
iv. Data warehousing and analytic processing;
v. Data archiving (backup and replication); and
vi. Data deletion and disposal.

To deploy an RFID system in a large-scale, a lot of readers and tags are needed. This scenario will contribute to a higher system complexity and the performance related problems will arise (Bolić*, et al.*, 2010). One of them is limited read range of RFID reader (Al-Ali*, et al.*, 2007).

The RFID reader read-rate also depends on the orientation of tags and the content of package that the tag is mounted to (Al-Ali*, et al.*, 2007; Clarke*, et al.*, 2006). In 2006, a research carried out by Robert H. Clarke *et al* manages to find out that the read rate of RFID tags is strongly affected by content of package and orientation of tags. In the research, the detected tags were only 25% because these tags are mounted on boxes filled with bottles of water. Tags on rice-filled jars have much better read rates which was 80.6%. However, tags those are facing outwards and towards the direction of antenna have better read rates compared to tags that are facing downwards. This scenario need to be taken into account by companies who intends to deploy RFID technology (Clarke*, et al.*, 2006; Glover and Bhatt, 2006). A survey on the latest RFID products in the market is also crucial for knowing that there is a solution for such problem.

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